A Review on Parametric Optimization in Wire Electic Discharge Machining

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Abstract— Wire-electro discharge machining (WEDM) has become an important non-traditional machining process, as it provides an effective solution for producing components made of difficult-to-machine materials like titanium, zirconium, etc., and intricate shapes, which are not possible by conventional machining methods. Due to large number of process parameters and responses lots of researchers have attempted to model this process. This paper reviews the research trends in WEDM on relation between different process parameters, include pulse on time, pulse off time, servo voltage, peak current, dielectric flow rate, wire speed, wire tension on different process responses include material removal rate (MRR), surface roughness (Ra), sparking gap (Kerf width), wire lag (LAG) and wire wear ration (WWR) and surface integrity factors. Optimization of process parameters is necessary to reduce cost and time of manufacturing. Various optimization and relation finding methods are shown here which are frequently used by researchers. Few conclusions based on existing literature have been extracted from existing literature on optimization of WEDM process parameters.

Key words: WEDM, LAG, WWR

I. INTRODUCTION

Wire electrical discharge machining (WEDM) was first introduced to the manufacturing industry in the late 1960s. The development of the process was the result of seeking a technique to replace the machined electrode used in EDM. Wire electrical discharge machining is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05–0.3 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the workpiece and the wire, eliminating the mechanical stresses during machining.

WEDM is a thermo-electrical process in which material is eroded from the work material by a series of separate sparks between the work material and the wire electrode i.e. tool (wire) and workpiece material, separated by a thin film of dielectric fluid (Distilled water oil) that is continuously fed to the machining zone to flushing away the evaporated particles. The movement of wire is controlled numerically to achieve the desired 3D (3-dimensional) shape and accuracy of the work piece. In addition, the WEDM process is able to machine exotic and high strength and temperature resistive (HSTR) materials and eliminate the geometrical changes occurring in the machining of heat-treated steels.

After computer numerical control (CNC) system was initiated into WEDM that brought about a major evolution of the machining process. As a result, the broad capabilities of the WEDM process were extensively exploited for any through-hole machining owing to the wire, which has to pass through the part to be machined. The common applications of WEDM include the fabrication of the stamping and extrusion tools and dies, fixtures and gauges, prototypes, aircraft and medical parts, and grinding wheel form tools.

Wire EDM often uses a steel wire that has been coated with brass, tungsten wire and other materials of good conductivity, with high strength and high melting temperature. The electrode material (wire) has to be matched to the work material so that in-process variations are controlled accurately. WEDM process is commonly conducted on underwater condition in a tank fully filled with dielectric fluid. While both conditions (submerged or dry machining) can be accomplished, very important is to produce a good quality of surface roughness and dimensional accuracy.

A. *Cutting Mechanism In Wire EDM:*

The main concept of WEDM is shown in Figure 1. In this process, a gently moving wire passes through a recommended path and removes material from the work piece. WEDM uses electro-thermal mechanisms to cut electrically conductive materials. The material is removed by a continuous of sparks between the wire electrode and the work material in the presence of dielectric (distilled water), which creates a path for each discharge as the fluid becomes ionized in the gap between tool (wire) work material. The area where discharge takes place is heated to extremely high temperature, so that the surface is evaporated and removed. The removed particles are flushed away by the flowing dielectric which shown in Figure 1. The wires materials for WEDM are made of brass, copper, tungsten, etc. (0.02 – 0.3mm in diameter) which capable to achieve very small corner radii. The wire used in WEDM process should be high tensile strength and very good electrical conductivity

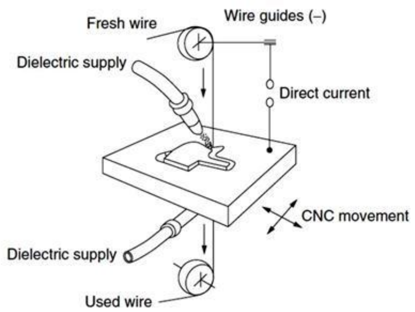

Fig. 1: Working principle of WEDM [B1]

B. Process Of WEDM:

The melting temperature of the parts to be machined is an important factor for this process rather than strength or hardness. The WEDM process makes use of electrical energy generating a channel of plasma between the cathode and anode, and turns it into thermal energy at a temperature in the range of 8000–12,000°C or as high as 20,000°C initializing a substantial amount of heating and melting of material on the surface of each pole. When the pulsating direct current power supply occurring between 20,000 and 30,000 Hz is turned off, the plasma channel breaks down. This causes a sudden reduction in the temperature allowing the circulating dielectric fluid to implore the plasma channel and flush the molten particles from the pole surfaces in the form of microscopic debris.

C. Process Parameters and Influence:

1) Pulse ON Time:
It controls the length of time that electricity is applied to the wire (per spark). Higher the Pulse on time increases the cutting speed because it generates more energy, but increase in pulse on time decrease the surface roughness. More increase in pulse on time may leads to wire breakage.

2) Pulse off Time:
Pulse off time turn off the electricity applied between the electrodes. Pulse off time is very important since during off time particles are flushed out of the gap. Increasing off time mean slower cutting, increased stability and less wire breakage. The off time also governs the stability of the process. But, sufficient pulse off time increases the machine efficiency but insufficient pulse off time may slow down the process.

3) Peak Current:
Peak current controls the range of current supplied to the wire to produce the spark. Increase in peak current with pulse on time increases the cutting rate, but it decreases the surface roughness.

4) Voltage:
Voltage is a function of work piece thickness. The thicker material requires more voltage, because erosion of higher thicker material requires voltage to spread over the whole area of cutting.

5) Servo Voltage:
Servo voltage sets the gaps voltage between two electrodes. Lower settings of voltage make smaller gaps, but too lower voltage makes the unstable process because the particles are trapped between the two electrodes gaps. This parameter controls cutting performance and over burn.

6) Wire Speed:
It is the rate at which the wire passes through the work piece and is controlled by the speed of the pinch rollers. Faster wire speed for roughing and a slower wire speed for finishing. When roughing, the wire will usually be under a great deal of power and stress this results in pitting on the wire and reduction of the wire diameter. By increasing the wire speed, wire breakage can reduce.

7) Wire Tension:
Stretching Pressure‖ applied from the tension roller to the wire ejection rollers. This is a gram-equivalent load with which the continuously fed wire is kept under tension so that it will remain straight between the wire guides. Wire vibration is controlled by the wire tension.

During roughing, wire will be under a great deal of stress due to the high power. This excessive stress having too much tension on the wire, causing wire breaks. Generally, slightly lower wire tension during roughing and a higher tension for finishing.

D. Optimization Methods:

- In highly competitive manufacturing industries nowadays, the manufactures ultimate goals are to produce high quality product with less cost and time constraints. To achieve these goals, one of the considerations is by optimizing the machining process parameters.
- Optimization is the act of obtaining the best result under given circumstances. In design, construction, and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decision variables.
- Optimization can be defined as the process of finding the conditions that give the maximum or minimum value of function under given constraints. The various methods that used in optimization can be described as below.

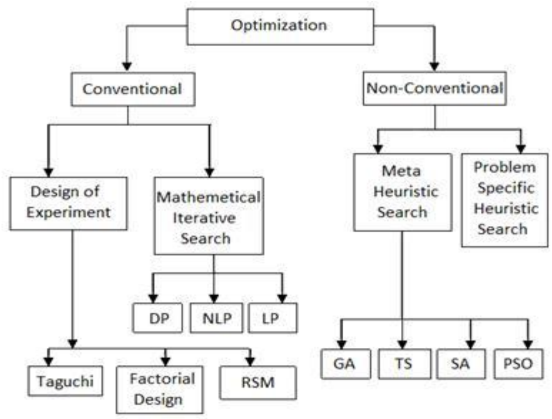

Fig. 2: Optimization Techniques [1]

E. Non-Traditional Optimization Algorithms:

In recent years, some optimization methods that are conceptually different from the traditional mathematical programming techniques have been developed. These methods are labelled as modern or non-traditional methods of optimization. Most of these methods are based on certain characteristics and behavior of biological, molecular, swarm of insects, and neurobiological systems. The following methods are comes under non-traditional optimization methods:

1) Genetic algorithms
2) Simulated annealing
3) Particle swarm optimization
4) Ant colony optimization
5) Artificial bee colony algorithm (ABC)
6) Sheep flock algorithm (SFA)
7) Biogeography-based optimization (BBO)
8) Fuzzy optimization
9) Neural-network-based methods

Most of these methods have been developed only in recent years and are emerging as popular methods for the solution of complex engineering problems. Most require only the function values (and not the derivatives).

The genetic algorithms are based on the principles of natural genetics and natural selection.

Simulated annealing is based on the simulation of thermal annealing of critically heated solids. Both genetic algorithms and simulated annealing are stochastic methods that can find the global minimum with a high probability and are naturally applicable for the solution of discrete optimization problems.

The particle swarm optimization is based on the behavior of a colony of living things, such as a swarm of insects, a flock of birds, or a school of fish.

Ant colony optimization is based on the cooperative behavior of real ant colonies, which are able to find the shortest path from their nest to a food source. In many practical systems, the objective function, constraints, and the design data are known only in vague and linguistic terms [B2].

In Artificial bee colony algorithm (ABC) algorithm, the position of a food source represents a possible solution to the considered optimization problem and the nectar amount of the food source is proportional to the quality or fitness of the associated solution.[2]

Sheep flock (SF) algorithm is a new evolutionary computation method based on sheep flocks heredity. When several sheep of one flock are inevitably mixed with the other flocks, the characteristics of the sheep in the neighboring flocks can be inherent to the sheep in other flocks in this occasion. Then, in the field, the flock of the sheep which has better fitness characteristics breeds most. [2]

The fundamental idea behind BBO algorithm is how species migrate from one island to another, how new species arise, and how species become extinct.[2]

Fuzzy optimization methods have been developed for solving such problems.

In neural-network-based methods, the problem is modelled as a network consisting of several neurons, and the network is trained suitably to solve the optimization problem efficiently.

II. Existing Literature

A. Literature Based On Process Parameters Optimization:

Norfadzlan Yusup et al.[1] have investigated to achieve manufacturing goals to produce high quality product with less cost and time constraints, one of the considerations is by optimizing the machining process parameters such as the cutting speed, depth of cut, radial rake angle. Five techniques are considered, namely genetic algorithm (GA), simulated annealing (SA), particle swarm optimization (PSO), ant colony optimization (ACO) and artificial bee colony (ABC) algorithm. It was found that GA was widely applied by researchers to optimize the machining process parameters. Multi-pass turning was the largest machining operation that deals with GA optimization. In terms of machining performance, surface roughness was mostly studied with GA, SA, PSO, ACO and ABC evolutionary techniques.

X.Y. Koua et al.[3] presented a new method for the optimal design of Functionally Graded Materials (FGM). Instead of using the widely used explicit functional models for optimal design of functionally graded material (FGM), a feature tree based procedural model is proposed to represent generic material heterogeneities.

Using the nature-inspired Particle Swarm Optimization (PSO) method, functionally graded materials with generic distributions can be efficiently optimized. We demonstrate, for the first time, that a PSO based optimizer outperforms classical mathematical programming based methods, such as active set and trust region algorithms, in the optimal design of functionally graded materials.

Thitipong Navalertporn et al.[4] proposed an integrated optimization approach using an artificial neural network and a bidirectional particle swarm. The artificial neural network is used to obtain the relationships between decision variables and the performance measures of interest, while the bidirectional particle swarm is used to perform the optimization with multiple objectives. Finally, the proposed approach is used to solve a process parameter design problem in cement roof-tile manufacturing. A confirmatory experiment was carried out with the obtained optimal parameter combination and indicated a production yield increase from 60% to 97%, which validated the capability of the approach.

Hsien-Ching Chen et al.[5] used method integrating back-propagation neural network (BPNN) and simulated annealing algorithm (SAA) is proposed to determine an optimal parameter setting of the WEDM process. The specimens are prepared under different WEDM process conditions based on a Taguchi orthogonal array table. The results of 18 experimental runs were utilized to train the BPNN predicting the cutting velocity, roughness average (Ra), and roughness maximum (Rt) properties at various WEDM process conditions and then the SAA approaches was applied to search for an optimal setting. In addition, the analysis of variance (ANOVA) was implemented to identify significant factors for the WEDM process and the proposed algorithm was also compared with respect to the confirmation experiments.

S. Sarkar et al.[6] studied wire electrical discharge machining (WEDM) of γ titanium aluminide. A feedforward back-propagation neural network is developed to model the machining process. The three most important parameters – cutting speed, surface roughness and wire offset – have been considered as measures of the process performance. The model is capable of predicting the response parameters as a function of six different control parameters, i.e. pulse on time, pulse off time, peak current, wire tension, dielectric flow rate and servo reference voltage.

It was observed that the surface quality decreases as the cutting speed increases and they vary almost linearly up to a surface roughness value of 2.44 μm and a cutting speed of 2.65 mm/min. beyond this value of cutting speed, surface roughness deteriorates drastically.

B. Literature Based On Comparison Of Optimization Methods:

Arindam Majumder [7] established new technique of combining neural network and optimization method. He compared three evolutionary algorithms coupled with back propagation neural network model for optimization of electric discharge machining process parameters. He took pulse on time, pulse off time and current as input parameters and material removal rate and wear ratio as output parameters. Objective was to find input parameters which maximize material removal rate and minimize surface roughness.

Comparison of SA, GA and PSO: He compared Genetic Algorithm, Simulated Annealing and Particle swarm optimization for their efficiency.

Methods and fitness value achieved

Optimization Technique	Fitness Values Achieved	Population Size
SA	0.54881	1
GA	0.54998	20
PSO	0.5463	15

Table 1: Methods and fitness value achieved

He showed by above values that PSO achieves lowest (best) fitness value with limited time, compared to SA and GA. However SA is single point optimization and thus easy to understand and program than GA and PSO.

Rajarshi Mukherjee et al.[8] finds the optimal values of different process parameters, such as pulse duration, pulse frequency, duty factor, peak current, dielectric flow rate, wire speed, wire tension, effective wire offset of wire electrical discharge machining (WEDM) process is of utmost importance for enhanced process performance. They attempted to apply six most popular population-based non-traditional optimization algorithms, i.e. genetic algorithm, particle swarm optimization, sheep flock algorithm, ant colony optimization, artificial bee colony and biogeography-based optimization for single and multi-objective optimization of two WEDM processes.

It is found that although all these six algorithms have high potential in achieving the optimal parameter settings, but the biogeography-based algorithm outperforms the others with respect to optimization performance, quick convergence and dispersion of the optimal solutions from their mean. Thus, the BBO algorithm can be used as a global optimization tool for finding out the parametric combinations of other machining processes too.

Rong Tai Yang, et al.[9] used hybrid method including response surface methodology (RSM) and back-propagation neural network (BPNN) integrated simulated annealing algorithm (SAA) were proposed to determine an optimal parameter setting for cutting tungsten. The results of 18 experimental runs via a Taguchi orthogonal table were utilized to train the BPNN to predict the MRR, quality performance of roughness average (Ra), and corner deviation (CD) properties. Confirmation experiments show that the MRR, Ra, and CD are 0.2925 g/min, 1.3125 μm, and 0.0274 mm, respectively. By comparison, the BPNN/SAA approach produced better predictions of the confirmation results than the RSM method.

T.A. Spedding & Z.Q. Wang et al.[10] presented an attempt at modeling the process through Response Surface Methodology and Artificial Neural Networks. A response surface model based on a central composite rotatable experimental design, and a 4-16-3 size back-propagation neural network have been developed. The pulse-width, the time between two pulses, the wire mechanical tension and the injection set-point are selected as the factors (input parameters), whilst the cutting speed, the surface roughness and the surface waviness are the responses (output parameters). Response surface methodology and artificial neural networks models have been developed for the wire EDM process, experiments showing that both of the models are able to predict the process performance, such as cutting speed, surface roughness, surface waviness within a reasonable large range of input factor levels. In the investigating area, the ANN model is found to fit the data better and have higher predictive capability to Ra and the cutting speed.

Ali Vazini Shayan et al.[11] have presented parametric study of dry wire EDM (WEDM) process of cemented tungsten car-bide. Experiments have been conducted using air as dielectric medium to investigate effects of pulse on time, pulse off time, gap set voltage, discharge current and wire tension on cutting velocity (CV) surface roughness (SR) and oversize (OS). Then a central composite rotatable method was employed to design experiments based on response surface methodology (RSM). Empirical models were developed to create relationships between process factors and responses by considering to analysis of variances (ANOVA). To increase the predictability of the process, intelligent models have been developed based on back-propagation neural network (BPNN) and accuracy of these models was compared with mathematical models based on root mean square error (RMSE) and prediction error percent (PEP). In order to select optimal solutions in the cases of single-objective and multi-objectives optimization problems, optimization includes two main approaches. First approach was based on mathematical model and desirability function. Also second approach was designed based on neural network and particle swarm optimization.

Liang Gao et al.[12] determined a novel parameters optimization method based on the cellular particle swarm optimization (CPSO). In the milling process, the selection of machining parameters is very important as these parameters determine the processing time, quality, cost and so on, especially in the high-accuracy machine tools. To address the constraints efficiently, the proposed method combines two constraints handling techniques, including the penalty function method and the constraints handling strategy of PSO.

The convergence rate of CPSO is a little faster than PSO, All of these reveal that the CPSO algorithm has a better and more stable performance than the previous ABC and PSO algorithm in the parameter optimization of multi-pass milling process parameter optimization problem.

Probir Saha et al.[13] utilized a second order multi-variable regression model and a feed-forward back-propagation neural network (BPNN) model to correlate their input process parameters, such as pulse on-time, pulse off time, peak current, and capacitance with the performance measures namely, cutting speed and surface roughness while wire electro-discharge machining (WEDM) of tungsten carbide-cobalt (WC-Co) composite material. It is seen that a 4-11-2 neural network architecture provides the best prediction capability with 3.29% overall mean prediction error, while 6.02% that of by regression model. Though the proposed regression model is adequate and accepted, BPNN yields better prediction. It is observed that the regression model is quite comparable to BPNN for cutting speed prediction.

Y. Wang, J.H. Liu et al.[14], finds the chaos method to provide the preferable assembly sequences of each particle in the current optimization time step, assembly sequence planning of complex products is difficult to be tackled. Then, the preferable assembly sequences are considered as the seeds to generate the optimal or near-optimal assembly sequences utilizing the traditional PSO algorithm. The results and analysis of the application validate that the CPSO algorithm has better effectiveness than the traditional PSO and SA algorithm.

However, the CPSO algorithm may be inadequate for solving the assembly sequence planning problem of large assemblies because the computation is explosively heavy

III. Conclusion

After comprehensive study of existing literature in machining parameter optimization in WEDM, following conclusions have been made:

- Many researchers have used different DOE techniques like Full factorial, Taguchi, Response surface design for experimental design from which it is found that the full factorial is the best method because it gives all the possible pair of selected parameter to study a large number of variables.
- The overall predictive performance of Particle Swarm Optimization technique is better than other methods. Genetic Algorithms is also preferable if we have more number of inputs and analysis time.
- Today, Most of machining parameter optimization work are being done by finding the output parameter function with neural network, which majorly replaced the conventional regression analysis technique. Latest algorithms and fast processors today make training the neural network easy and also ensure better result

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